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Cognitive load influences the evaluation of complex acoustical scenarios

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Abstract

Sound evaluations depend on sound characteristics as well as on situational and person-related factors. Aim of the study was to investigate the effects of temporal dynamics of a sound, a person's cognitive load, personality traits (noise sensitivity, extraversion) and their interactions on the overall retrospective evaluation of complex acoustical scenarios. In the course of a laboratory experiment, 62 participants were presented eight two-minute sound examples, whereby the position and valence of the peaks were varied. Task of an experimental group was to perform the so-called Stroop test of color-to-word interference during the sound presentation, and to retrospectively rate the sounds in terms of loudness and pleasantness. A control group only rated the sounds during and after listening to them. Results revealed that, on average, participants in the "inattentive" experimental group rated the sounds as 6.6% less loud and 6.7% more pleasant compared to the participants of the "attentive" control group. Peak position and valence also showed main effects but did not interact with the effect of the treatment. Moreover, personality traits did not have a significant main or moderating effect on sound evaluations. Findings highlight the important role of cognitive load and attention on the evaluation of complex acoustical scenarios.

Keywords: Sound evaluations; Attention; Cognitive load; Retrospective judgments; Personality

1 INTRODUCTION

Human evaluations of our acoustical environment depend on multiple factors, such as features of the sound, psychological characteristics of the listener or the context in which the evaluation takes place. While research on the influence of sound properties on perception and evaluation was widely investigated in psychoacoustical research [1, 2], the role of the listener received less attention. Also, it is widely unknown how sound and listener characteristics interact within the evaluation process.

1.1 Listener state – Influences of attention and cognitive load

One of the crucial factors influencing sound evaluations is the current attention of the listener. Attention can be described as the process of selecting information that is important for current action and perceptual goals and suppressing irrelevant information. The focus of attention can either be directed deliberately (for example, on a certain speaker) or steered automatically in response to a salient sensory input (focusing on the cause of the stimulus). In our study, we follow a cognitive load theory of attention in which the perception or rejection of an (acoustical) stimulus is assumed to depend on the level of cognitive load (defined as the used amount of working memory resources) associated with a certain distracting task [3].

Opposed to many psychoacoustical experiments, the listener's attention in a real-life situation is not always focused on the acoustical environment, especially when it comes to non-speech sounds. This might lead to biases when predicting annoyance reactions in mundane life by results from laboratory studies. Empirical evidence suggests that sounds from household appliances are perceived as more pleasant in everyday-like environments in which the participants' attention is not solely focused on the acoustical stimulus, compared to experiments where only sounds of the devices are presented [4]. This is corroborated by early studies of attention on vision which demonstrated that unattended information typically goes unnoticed [5].

1.2 Listener traits – Influences of personality

Cognitive and emotional processes (such as those involved in sound evaluations) can be further related to various stable personality traits and information processing styles which might explain differences in sound evaluations across individuals. Presumably the most important trait in the context of this paper is noise sensitivity which covers attitudes toward different kinds of environmental sounds [6]. Furthermore, the Big Five personality trait Extraversion has repeatedly been connected to effects of background sounds and music on the execution of comprehension and problem solving tasks [7]. Finally, several traits such as Neuroticism and the information processing style have be shown to interact with situational variables (e.g., company of others) when it comes to sound evaluations [8].

1.3 Sound characteristics – Influences of the temporal dynamics of a sound

When discussing the role of attention / inattention on sound perception and evaluation, one must consider that, as mentioned above, certain sounds are capable of modulating the listener's attention due to their salient characteristics (e.g., loudness, temporal and spectral fluctuations). The important role of peaks (i.e., salient events) on overall loudness and pleasantness judgments of time-varying environmental sounds have already been demonstrated in various studies [8, 9]. Furthermore, it has been shown that later sound events play a more important role in predicting retrospective sound evaluations than other sections (recency effect; [10]). The fact that retrospective judgments can be predicted only by the unweighted combination of peak and the end was established by Kahneman and colleagues as the so-called 'peak-end rule' [11]. In this context, Steffens, Steele & Guastavino (2017) observed that a weighted combination of peak and end can explain a large proportion of variance in daily retrospective judgments of environmental sounds [8].

1.4 Sound and listener characteristics and their interaction – The current study

One major aim of the current study was to investigate the influence of inattention in the course of increased cognitive load caused by a distracting task on pleasantness judgments of environmental sounds. Based on the literature, we hypothesized that inattentive participants would rate sounds as significantly more pleasant and less loud than attentive participants (H1). With regard to the temporal position of salient events (peaks), we assumed that the later a negative valence peak (peak levels higher than level values of the rest of the sound) is positioned in a sound scenario, the louder and more unpleasant the sound will be judged, regardless the attentional state of the participant (H2a). Analogously, we expected that the later peaks with positive valence occur in a sound scenario, the lower the overall unpleasantness and loudness would be rated (H2b).

Concerning the role of personality, we assumed that participants scoring high on Extraversion and executing a task while listening would judge test sounds as less loud and more pleasant than participants scoring low on Extraversion (H3), due to a lower interference of the task execution [7]. Finally, potential interactions between sound and listener characteristics were explored without formulating specific hypotheses.

2 METHOD

2.1 Participants

The study involved 63 participants aged between 20 and 63 years (27% female; mean age: 29.5, SD = 7.9). Twenty participants were contacted via the TU Berlin mailing list of active study participants and received 10 € as compensation. The remaining 43 participants were students of the TU Berlin who could acquire credit points for participating. Requirements for participation were normal hearing, sufficient knowledge of German and no color blindness. The data set of one participant was excluded from the evaluation due to the fundamentally incorrect execution of the task.

2.2 Stimuli

Nine different two-minute sound scenarios taken from the sound database General Series 6000 were used for the study. Six of the scenarios, referred to as test sounds, consisted of a constant background sound (base) interrupted by another twenty-second sound event (peak). The sounds were divided by "peak types" into groups of three. One group contained sounds with low peaks (peak level lower than background sound), the other sounds with high peaks (peak level higher than background sound). The peaks were located after 10 seconds (early), 50 seconds (middle), or 90 seconds (late) for each condition (see Figure 1). In addition, a training sound and two filler sounds were compiled. The latter were used to distract the participants from the regular structure of the sounds during the sequential presentation. The structure and composition of the sounds are described in Table 1.

2.3 Experiment setup and calibration

The sounds and tasks were presented to the participants using a laptop computer with Matlab software, an external audio interface (Focusrite Scarlett 6i6) and circumaural headphones (DT 770 Pro). For the calibration of the system, the loudest of the test sounds, the jackhammer sound, was used as the reference sound. Using an audio coupler, the volume of the sound was adjusted by matching the volume of the reference sound to that of a nearby construction site (ca. 50 m distance) of 85dB(A). After several test runs, the volume of the sounds with low peak was reduced to 75 dB(A) in order to make the acoustical stress caused by the significantly longer jackhammer sound tolerable for the participants (see Figure 1).

2.4 Experimental design

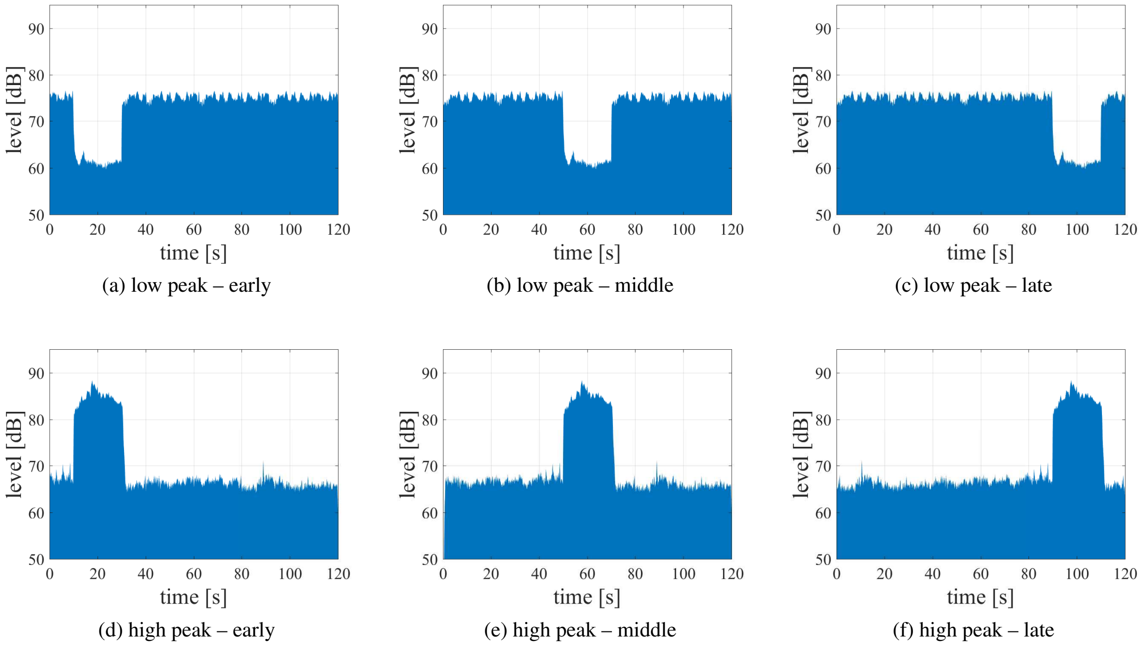
Participants were randomly assigned to an inattentive (experimental) and an attentive (control) group. Participants in the attentive group performed a listening task that drew their attention directly to the presented sounds. Participants of the inattentive group conducted the Stroop Color-Word Interference Test (see Section 2.4.1) during the presentation of the test sounds in order to constantly distract them from the acoustical stimuli. Test and filler sounds were successively presented to both groups in a randomized order; only the filler sounds were always placed in the third and sixth position. Filler sounds were used to distract the participants from the regular structure of the test sounds (peak type and peak position) in order to reduce anticipation errors and were excluded from the data analysis. After the presentation of each sound, the participants had to rate the loudness and pleasantness of the sounds via two sliders with 101 steps, ranging from "very quiet" to "very loud" and "very pleasant" to "very unpleasant".

At the end of the test, participants completed questionnaires including noise sensitivity [12], Extraversion [13], as well as the two information processing styles 'need for cognition' and 'faith in intuition' (German version of the Rational-Experiential Inventory; [14]). Need for cognition describes the tendency for systematic processing of information and indicates how much people enjoy cognitively strenuous activities, such as solving puzzles. Faith in intuition indicates how much people rely on intuitive decision-making.

2.4.1 Stroop Color-Word Interference Test (experimental group)

The Stroop Color-Word Interference Test is a concentration task in which a list of differently colored words is presented to a participant [15]. The words in the list describe different colors. However, the word information does not match the hue of the word. The task of the participant is either to read the words or to name their coloring. In the present study, we used the Stroop Test to distract the participants during the presentation of the test sounds and to ensure a constant cognitive load.

The computer-implemented Stroop Test was used in a slightly modified form. The participants were presented with lists of 15 words. These lists repeatedly contained the words blue, green, yellow and red in random order. Although the order was random, it was ensured that a color did not occur several times in succession. The



(a) low peak – early (b) low peak – middle (c) low peak – late

(d) high peak – early (e) high peak – middle (f) high peak – late

Figure 1. Level-Time-Diagram of the used test sounds.

limitation was put in place to prevent the occurrence of easily recognizable patterns during the test and, thus, to prevent fluctuations in test performance. Four buttons were positioned below the word list. Each button was labeled with one of the colors in black lettering. The task of the test was to assign the coloring of the current word (indicated by a grey frame) as quickly and conscientiously as possible by pressing the corresponding button. After each assignment, the frame indicated the next word in the sequence. After assigning the last word in the list, a new list was generated and the frame was reset to the first position. The test was paused at the end of each two-minute test sound, and the participants were asked to evaluate the overall loudness and pleasantness of the acoustical scenario.

In addition to the evaluation criteria, the number of correct assignments as well as the response time between the assignments were recorded (not reported in this paper). It was assumed that the performance of the participants (number of correct answers and response time) could improve over the course of the test. This could have affected the cognitive load and thus the subsequent assessment of the sounds. In order to keep the performance as constant as possible, each participant completed a training sequence under supervision. This training sequence consisted of the Stroop Test accompanied by the training sound. Due to the rather simple task, a training period of two minutes was considered appropriate in order to reduce possible learning effects to a minimum while also keeping the cognitive load right before the test at a low level.

2.4.2 Listening Task (control group)

During the presentation of the sounds, participants in the control group were asked to continuously adjust a slider between "very quiet" and "very loud" to reflect the perceived loudness of the test sounds. The evaluation of overall loudness and pleasantness took place after each two-minute test sound. Contrary to the procedure used in the Stroop test, the purpose of the listening task was to draw the attention of the test participants to the test sounds.

Table 1. Description of the sound scenarios used in the study

Sound	Peak type	Peak position	Base	Peak	Base/Peak level [dBA]
1	low	early	Jackhammer	Noise + Birdsong	75 / 60
2	low	middle	Jackhammer	Noise + Birdsong	75 / 60
3	low	late	Jackhammer	Noise + Birdsong	75 / 60
4	high	early	Noise + Birdsong	Jackhammer	66 / 85
5	high	middle	Noise + Birdsong	Jackhammer	66 / 85
6	high	late	Noise + Birdsong	Jackhammer	66 / 85
7	/	/	Japanese Speech	/	75 / -
8	/	/	Café + Music	/	65 / -
9	high	middle	Birdsong + Train Rattle	Lawn Mower	60 - 70 / 80

Note: Sounds 7-9 only functioned as training or filler sounds and were not used for further analyses.

2.5 Data analysis

Data processing and analysis was performed using IBM SPSS 25.0. Before the main analyses, the relationship between the variables "loudness" and "pleasantness" was examined. Due to their high correlation ($r = -.717$; $p < .001$), both variables where collapsed into one factor unpleasantness by means of a Principal Component Analysis. This factor was scaled in a way that 100% unpleasantness corresponded to the ratings "very loud" and "very unpleasant", 0% to "very soft" and "very pleasant" and 50% to a neutral rating. Hypotheses were tested by means of several linear mixed-effects models including a random intercept for each participant and using restricted maximum likelihood estimates of variance components and Type III Analysis of Variance via Satterthwaite's degrees of freedom method.

3 Results

Before testing the hypotheses, a null model including only a random intercept for each participant was computed to obtain the Interclass Correlation Coefficient (ICC). This analysis showed that 27.4% of the overall variance of the judgments can be explained through person-related differences ($ICC_{total} = .274$, $ICC_{exp.} = .154$; $ICC_{control} = .356$). The ICCs for both groups revealed that sound evaluations in the attentive group varied more than twice as much across persons (35.6%) than they did in the inattentive group (15.4%).

In the next step, several linear-mixed effects were computed to test the hypotheses formulated in Section 1.4. Results confirmed our first hypothesis (H1) that participants in the inattentive group would perceive the test sounds as less loud and unpleasant than participants in the attentive group, $F(1, 60) = 7.17$; $p = .010$, $R^2_{marginal} = .039$. Figure 2 depicts the means and 95 % confidence intervals for the factor unpleasantness for both test groups (each with i = 31 observations) and grouped by peak type and peak position. When analyzing the two items loudness and pleasantness separately, results further revealed that participants in the inattentive group rated the test sounds 6.6% as less loud and 6.7% more pleasant than the inattentive group.

Concerning H2a, results confirmed our assumption that the peak position had a significant effect on the unpleasantness ratings for the high peak scenarios, $F(2,122) = 12.50$, $p < .001$, $R^2_{marginal} = .069$. As expected, the later high peaks occurred in a sound, the more unpleasant the respective sound scenario was evaluated by the participants. As illustrated by Figure 2, unpleasantness ratings increased over the peak positions "early", "middle" and "late" from 55.2% over 64.5% to 68.5% (early vs. late: $p = .001$; middle vs. early: $p = .007$) for the inattentive group and from 65.7% over 67.7% to 74.6% (early vs. late: $p = .031$) for the attentive group. This means that the differences in the ratings across the different peak positions were slightly larger for the inattentive group than for the attentive group, even though this difference was not significant ($p = .248$).

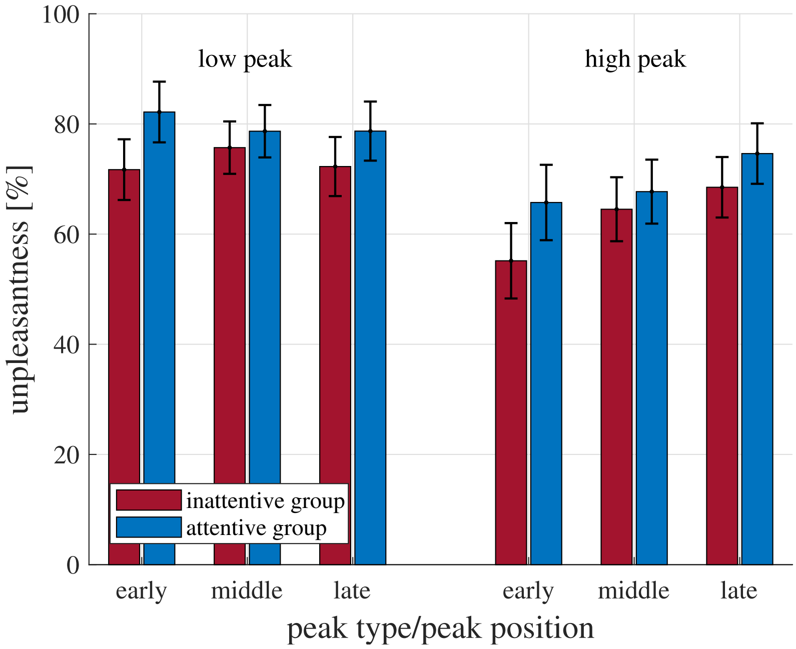


Figure 2. Means and 95% confidence intervals for the factor unpleasantness. The data was divided into inattentive (red) and attentive group (blue) sets and grouped by peak type and peak position.

Also, regarding the low peak scenarios, no significant differences between peak positions (H2b) were observed, $F(2, 122) = 0.88$, $p = .417$.

Moreover, Hypothesis 3 expected an influence of the personality trait Extraversion on the perceived unpleasantness of the sounds in the inattentive group. A linear mixed-effects model, however, revealed that Extraversion did not predict unpleasantness ratings, $F(1, 29) = 0.033$, $p = .857$. This is also the case when repeating this analysis for both test groups, $F(1, 60) = 0.586$, $p = .488$. Accordingly, analyses revealed no significant linear relationships between unpleasantness ratings in both groups and the other personality traits measured in the study (noise sensitivity, need for cognition, faith in intuition). Finally, no significant interaction effects between personality traits on the one hand and the condition and the peak position on the other hand predicting sound evaluations were obtained.

4 Discussion

This study investigated the role of (in-) attention and cognitive load and potential interactions with sound and listener characteristics on sound evaluations. Results confirmed our assumption that participants whose attention was directed to sounds presented in an experiment rated them as louder (6.6%) and less pleasant (6.7%) than those distracted by an additional task. This finding is in line with the literature [4, 5] and highlights the need for taking into account attentional processes when investigating sound evaluations. In addition, it suggests that results from psychoacoustical studies in which participants' attention is focused on test sounds might introduce a bias when predicting human loudness perception and annoyance reactions in mundane life.

Our study further replicated previous findings on the role of recency effects for negative sound events (high peaks). The recency effect suggests that is not only relevant whether but also when a certain sound event occurs, emphasizing the role of long-term memory processes in sound evaluations. It is worth mentioning that, in our experiment, the recency effect affected both the attentional and the inattentional group in the similar way. This finding indicates that, despite the shifted focus of attention and the resulting constant differences in overall unpleasantness judgments, participants in both groups seemed to rely on similar information when forming these judgments. Contrary to our hypothesis, however, a recency effect was not observed for evaluations of sounds with low (positive) peaks. This finding might be explained by a negativity bias meaning that negative information is processed more thoroughly than positive information [16, 17]. We therefore assume that high peaks have a higher likelihood to be memorized and recalled in the course of a retrospective judgment than low peaks.

In our study, personality traits were not related to sound evaluations, neither as main effect nor as a moderator. This contradicts findings from several studies showing significant but small correlations between the degree of noise sensitivity and loudness and unpleasantness ratings (e.g., [6]). However, in our study, a rather young sample reporting comparatively low mean noise sensitivity values conducted the study ($M = 22.4\%$, $SD = 3.9\%$; not reported in the results section). As noise sensitivity typically increases with age [18], the study should be replicated with a sample including a higher percentage of elderly participants to obtain significant relationships between personality and sound evaluations. Regarding the null effect of Extraversion in the inattentional group, our studies showed that introverts were in fact more affected in their test performance than extraverts (not reported in the results section), but that this was not related to the sound evaluation.

5 Conclusion

In our study, we demonstrated than (in-) attention and cognitive load of a listener significantly affects loudness and pleasantness ratings of complex sound scenarios. These findings have strong implications for research on noise effects and psychoacoustical metrics. For example, results obtained in focused laboratory studies might tend to overestimate actual loudness and unpleasantness judgments in real-life where the focus of people's attention is not solely focused on the acoustical environment. Amongst others, this might be relevant for practitioners in sound engineering and design when determining tolerance thresholds for acoustical product characteristics (e.g., the loudness of a washing machine).

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